# Panel: EVA-Human Modeling

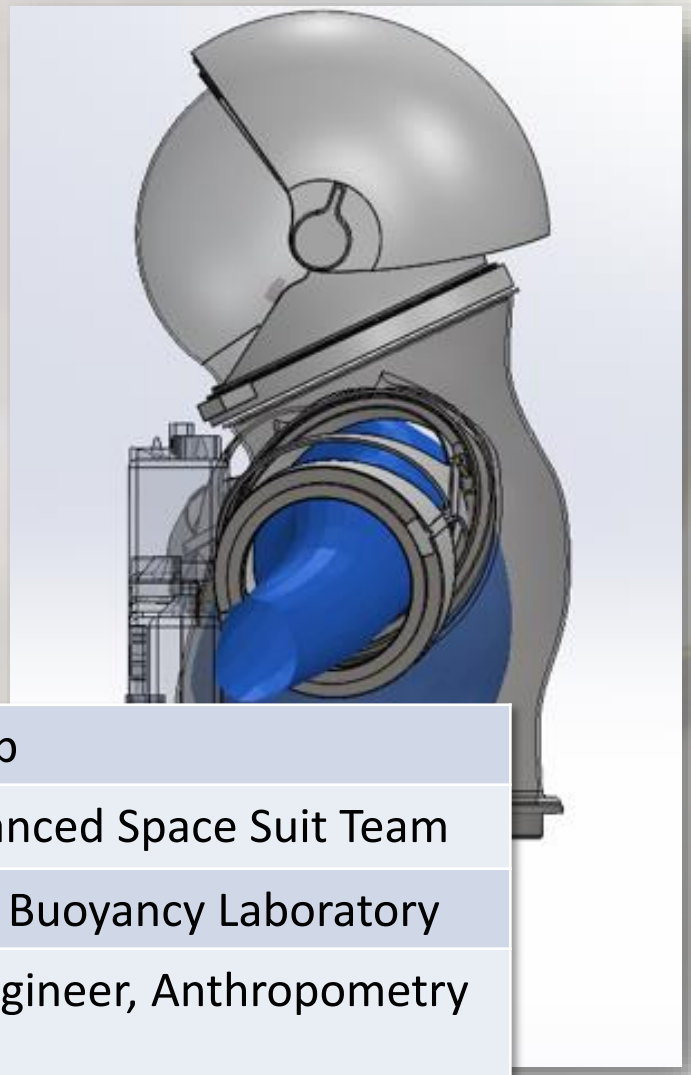
*Near-term applications, needs, and challenges of Human-Suit modeling capabilities to inform xEMU development*

18 October, 2017

Moderator: Andrew Abercromby

# Panel: EVA Human Modeling

- Panel Topic Description
- Panelist Presentations
- Q & A / Discussion
- Wrap-Up



| | |
|---|---|
| Andrew Abercromby | Lead – EVA Physiology Lab |
| Richard Rhodes | Space Suit Engineer, Advanced Space Suit Team |
| Bob Sanders | Medical Director, Neutral Buoyancy Laboratory |
| Han Kim | Human Factors Design Engineer, Anthropometry & Biomechanics Facility |
| Leia Stirling | Professor & Co-Director, MIT Man-Vehicle Lab |

# Panel: EVA Human Modeling

- *Topic Title: Near-term applications and needs of Human-Suit modeling capabilities to inform xEMU development.*
  - Focus on near-term applications of existing models rather than what we could do with better models 5-10 years from now.
  - Are our current models good enough to be helpful? Or do their limitations make them misleading?
  - What EVA-Human models do you already use, if any? What works and what doesn't work?
  - If models are not already being used, why not?
  - What are potential applications of model(s) to xEMU development if they are not already being used? What questions / problems can they address, how soon, and are these actually important problems?

# Suit Engineering & Modeling

RICHARD RHODES – SPACESUIT ENGINEER

ADVANCED SPACESUIT DEVELOPMENT TEAM

# Background

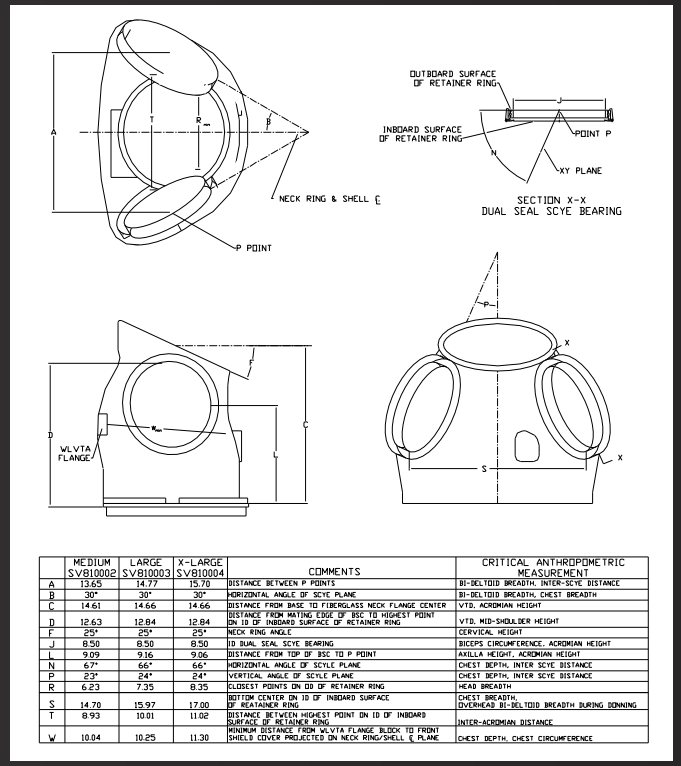
- Engineering Goal: Enable crew to perform EVA required tasks with the least amount of energy expenditure
  - If no specific tasks are identified, maximize mobility with a goal of achieving unsuited performance
- Mobility is a combination of:
  - Range of motion
  - Work or joint torque throughout that range of motion
  - Natural movement (programming)
- Mobility is also heavily impacted by fit
  - Fit is usually evaluated by how well the suit's mobility joints line up with the crew's joints throughout the required tasks

# Testing Limitations

- Development budgets usually do not allow multiple sizes of suits
  - Consistent subject fit and performance can be a challenge when evaluating suit architectures
  - Iterations of joint design are expensive and slow
    - Poor concept or just poor implementation
- Modeling suit fit and mobility offers a way of evaluating fit, range of motion, and natural movement of mobility architectures without building a fleet of suits
  - Models need to be validated, but can help guide development
- Examples of modeling efforts
  - Fit for Z-2 development

# Past Sizing Method

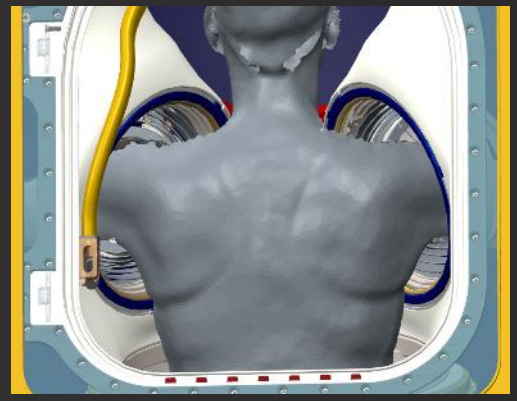
- Historical Sizing method (Mark III & EMU)
  - Identify population to fit
  - Identify locations on the suit that correspond to the critical anthropometric dimensions
  - Validate measurements by building a mockup structure and fit checking crew population
  - Results:
    - 2D measurements offer little guidance on sizing of population
    - Fit checking crew population ensures current astronauts will fit, but is not very predictive of future sizes




| | MEDIUM SV810002 | LARGE SV810003 | X-LARGE SV810004 | COMMENTS | CRITICAL ANTHROPOMETRIC MEASUREMENT |
|---|---|---|---|---|---|
| A | 13.65 | 14.77 | 15.70 | DISTANCE BETWEEN P POINTS | BI-DELTOID BREADTH, INTER-SCYE DISTANCE |
| B | 30° | 30° | 30° | HORIZONTAL ANGLE OF SCYE PLANE | BI-DELTOID BREADTH, CHEST BREADTH |
| C | 14.61 | 14.66 | 14.66 | DISTANCE FROM BASE TO FIBERGLASS NECK FLANGE CENTER | VTD, ACROMIAN HEIGHT |
| D | 12.63 | 12.84 | 12.84 | DISTANCE FROM MATING EDGE OF BSC TO HIGHEST POINT ON ID OF INBOARD SURFACE OF RETAINER RING | VTD, MID-SHOULDER HEIGHT |
| F | 25° | 25° | 25° | NECK RING ANGLE | CERVICAL HEIGHT |
| J | 8.50 | 8.50 | 8.50 | ID DUAL SEAL SCYE BEARING | BICEPS CIRCUMFERENCE, ACROMIAN HEIGHT |
| L | 9.09 | 9.16 | 9.06 | DISTANCE FROM TOP OF BSC TO P POINT | AXILLA HEIGHT, ACROMIAN HEIGHT |
| N | 67° | 66° | 66° | HORIZONTAL ANGLE OF SCYLE PLANE | CHEST DEPTH, INTER SCYE DISTANCE |
| P | 23° | 24° | 24° | VERTICAL ANGLE OF SCYLE PLANE | CHEST DEPTH, INTER SCYE DISTANCE |
| R | 6.23 | 7.35 | 8.35 | CLOSEST POINTS ON ID OF RETAINER RING | HEAD BREADTH |
| S | 14.70 | 15.97 | 17.00 | BOTTOM CENTER ON ID OF INBOARD SURFACE OF REATAINER RING | CHEST BREADTH, OVERHEAD BI-DELTOID BREADTH DURING DONNING |
| T | 8.93 | 10.01 | 11.02 | DISTANCE BETWEEN HIGHEST POINT ON ID OF INBOARD SURFACE OF RETAINER RING | INTER-ACROMIAN DISTANCE |
| W | 10.04 | 10.25 | 11.30 | MINIMUM DISTANCE FROM WL VTA FLANGE BLOCK TO FRONT SHELL COVER PROJECTED ON NECK RING/SHELL ℄ PLANE | CHEST DEPTH, CHEST CIRCUMFERENCE |

# Recent Modeling Based Sizing

- Z-2 Sizing Method
  - Identify population to fit
  - Obtain boundary manikins/scans to represent population
  - Conduct fit checks of manikins from entire population set in various positions
  - 3D print HUT structure and validate model results with subject fit checks
  - Results:
    - Offers better evaluation of 3D body shapes
    - Once validated, can easily fit check entire population size ranges
    - By evaluating multiple arm positions, we can evaluate good joint placement and sizes



# Future Needs

- Fit – Custom or Fleet Sizing
  - Modeling analysis to produce a predicted optimal fit for custom sizing
  - Modeling analysis to produce the best sizing across a fleet of suits and the number of suits
    - Combined with mobility analysis to predict mobility when not in optimal fit
- Mobility
  - Analysis of current mobility architecture to understand what aspects of the mobility architecture or joints could be improved to offer most natural movement or most efficient interaction with crew
    - Joint angle and position
    - Joint sizing and subject indexing
    - Bearing torque

# Exposure Incidence System (EIS) Then and Now

# Tracking the Human-Suit Interface

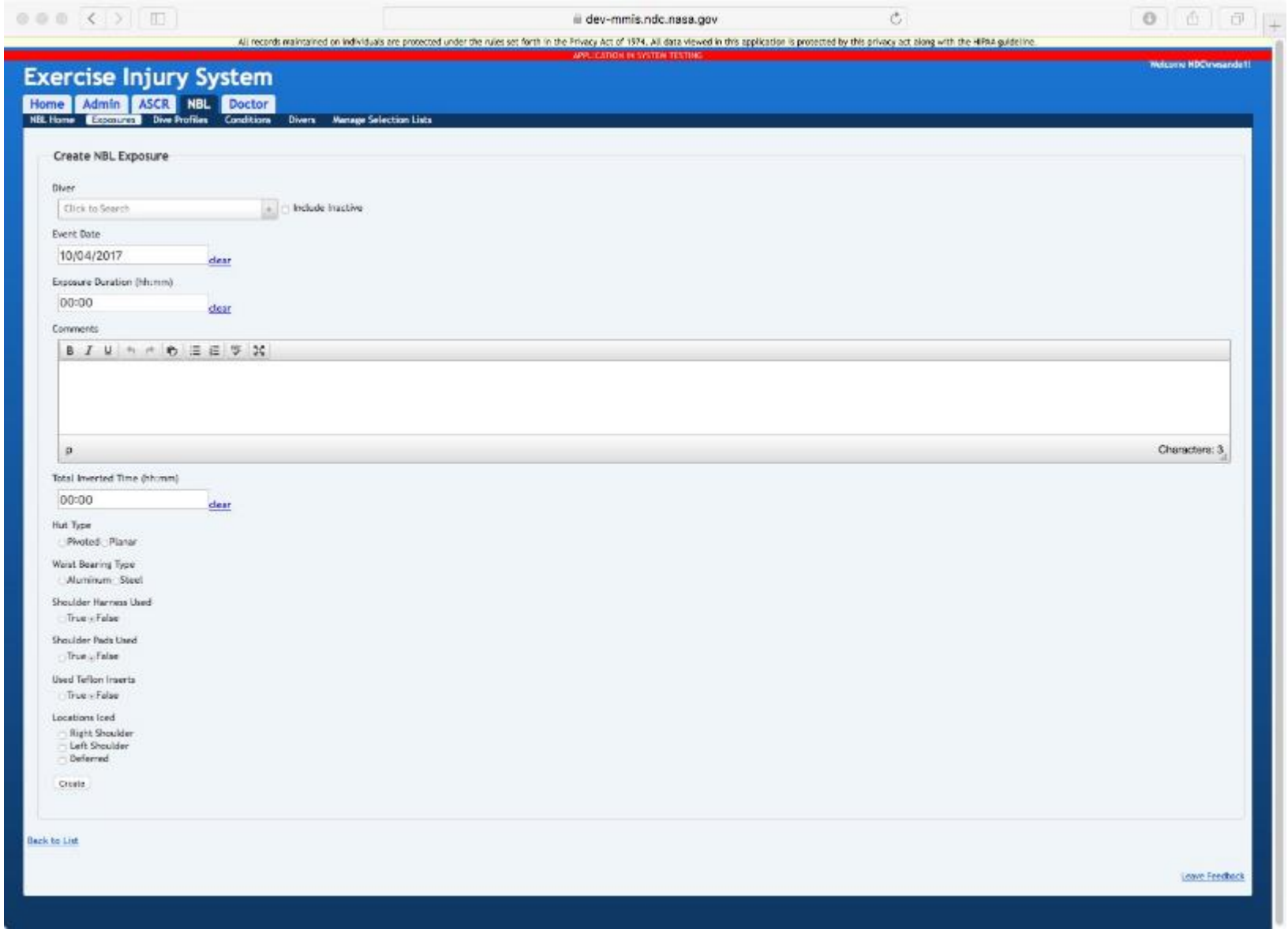
Robert W. Sanders, MD, FACEP, FUHM
NBL Medical Director (NASA-JSC)
Assistant Professor
University of Texas Medical Branch, Galveston

# The Problem

- Over the years we have identified several significant injuries
  - Shoulder injuries (Slap, rotator cuff)
  - Knee injuries (meniscal tears)
  - Fingernail Delamination
  - What else?

# Document to Prevent

- EIS



# Sometimes We Fail

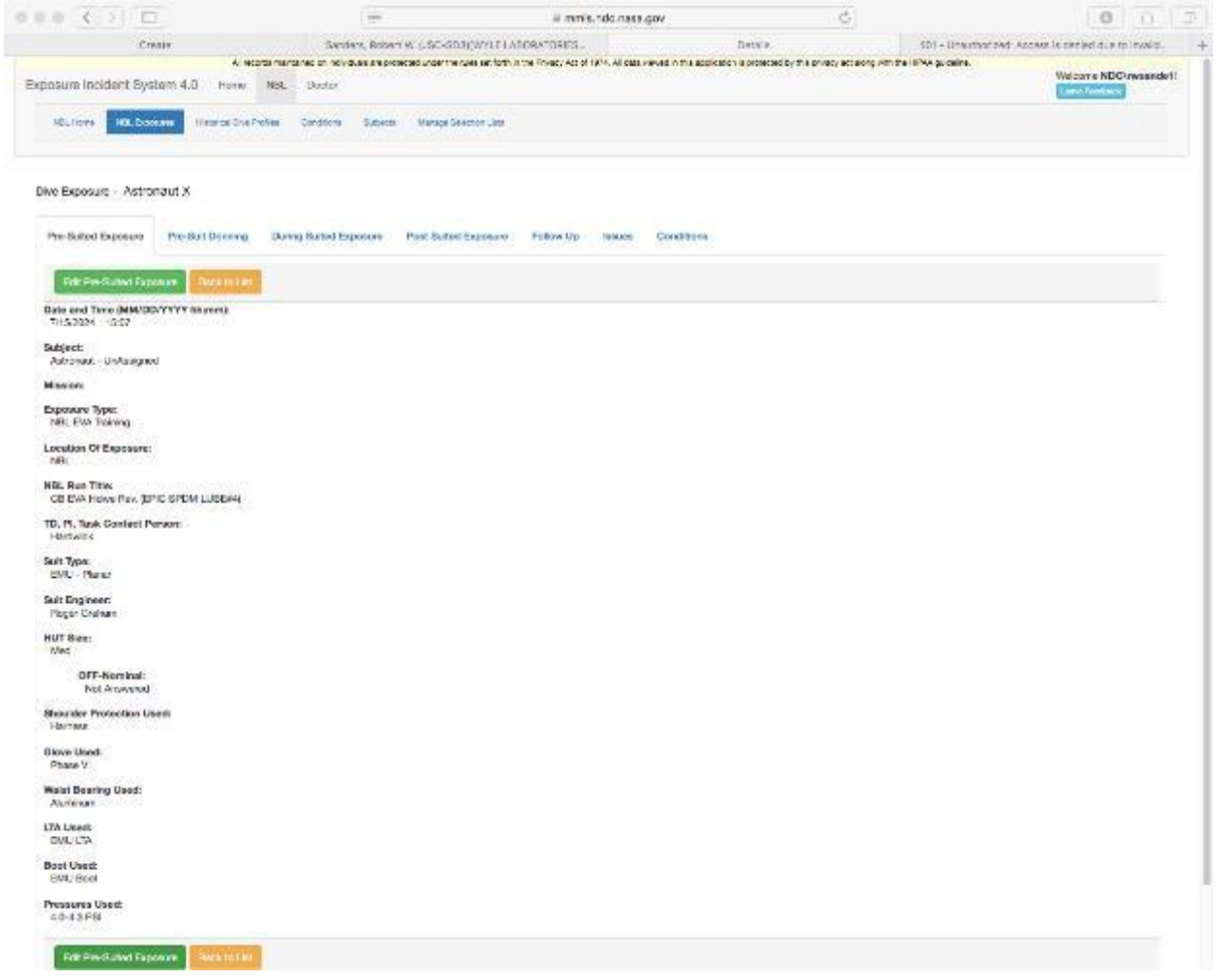
# EIS

- We have learned a lot
  - Shoulder injury prevention
  - ASCR Conditioning
  - Inverted Ops
  - Minimize repeated failed attempts

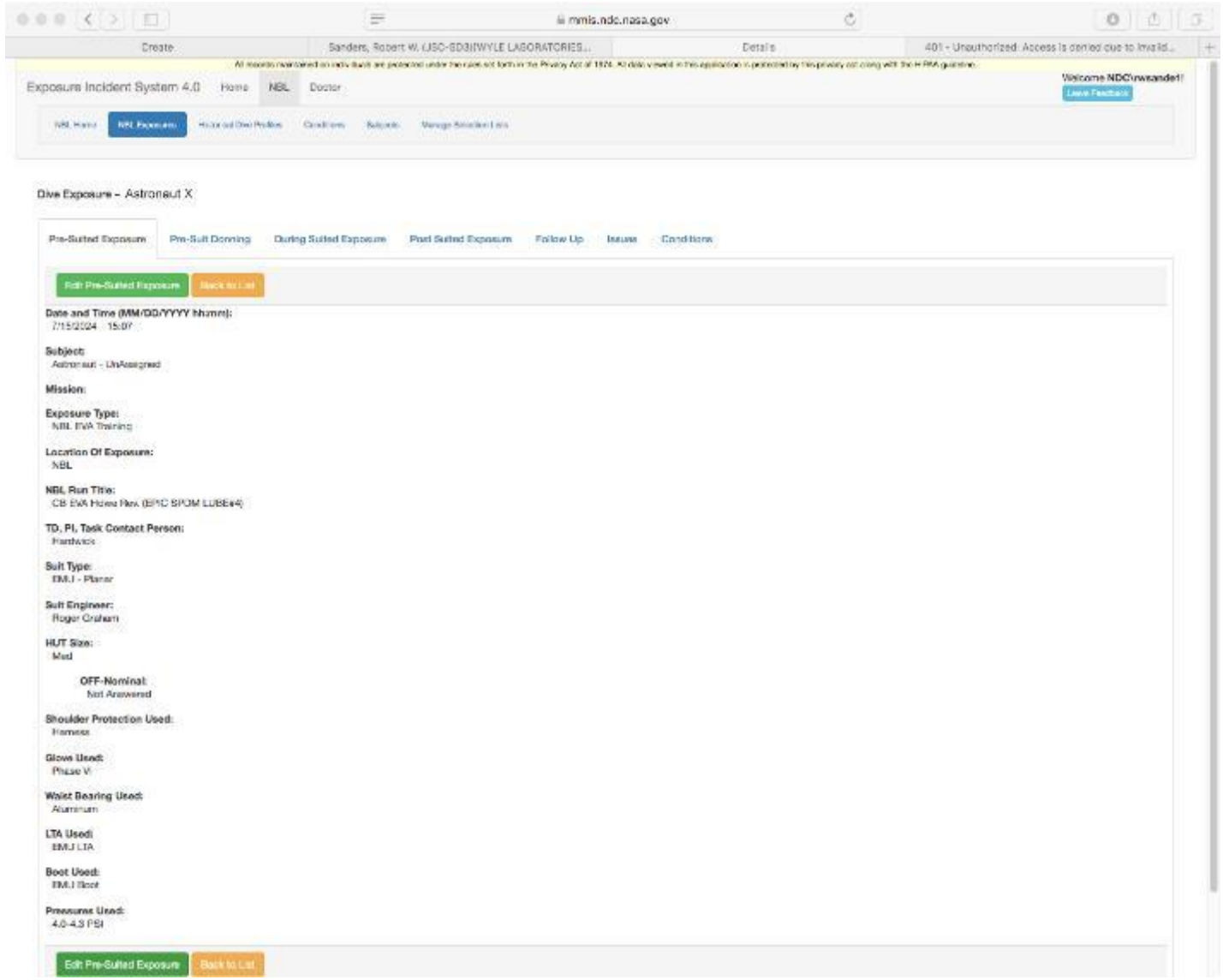
  - But learned from injury
  - Attributed to the suit

# EIS 2.0

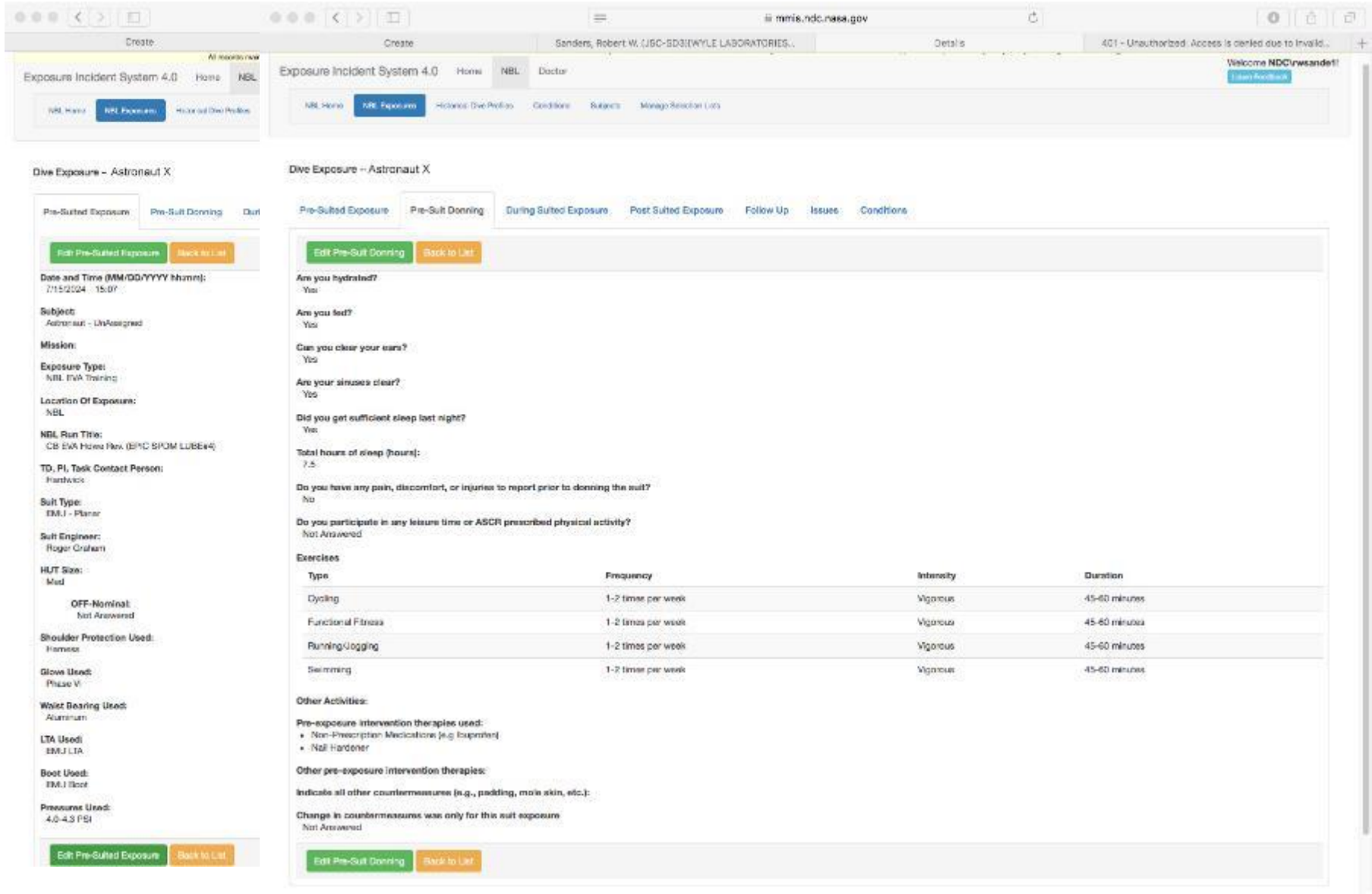
- Desire to learn more about the “pre-exposure” subject (vs. suit)
  - Prone to injury?
  - Sleep?
  - Hydration?
  - Activity level and type
    - Are they ready/fit?
  - Preexisting injury?



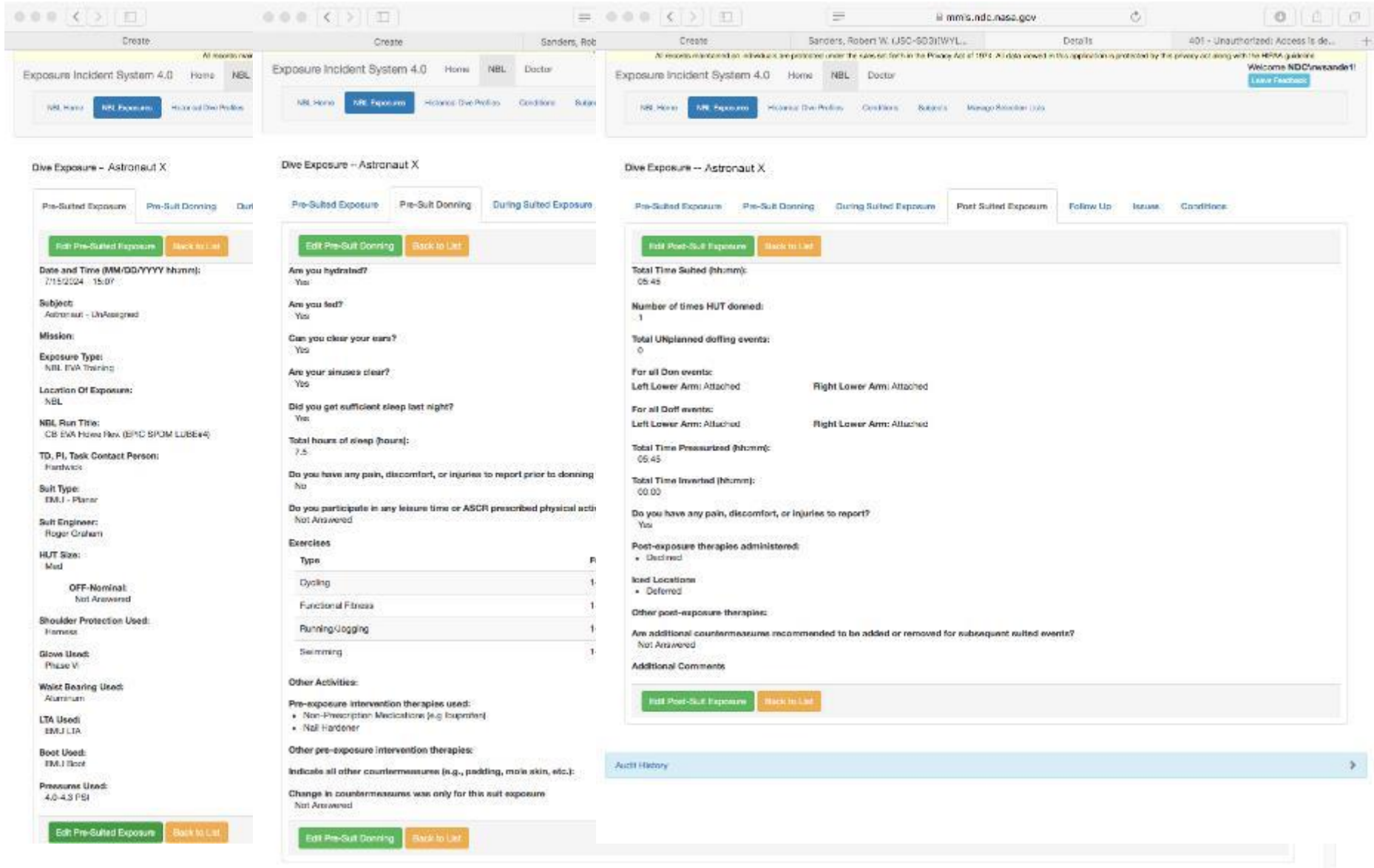
# EIS 2.0


mmis.ndc.nasa.gov
Exposure Incident System 4.0
Home
NBL
Doctor
Dive Exposure – Astronaut X
Pre-Suited Exposure
Pre-Suit Donning
During Suited Exposure
Post Suited Exposure
Follow Up
Issues
Conditions
Edit Pre-Suited Exposure
Back to List
Date and Time (MM/DD/YYYY hh:mm):
Subject:
Mission:
Exposure Type:
Location Of Exposure:
NBL Run Title:
TD, PI, Task Contact Person:
Suit Type:
Suit Engineer:
Roger Graham
HUT Size:
Med
OFF-Nominal:
Not Answered
Shoulder Protection Used:
Glove Used:
Phase VI
Waist Bearing Used:
Aluminum
LTA Used:
Boot Used:
Pressures Used:
4.0-4.3 PSI

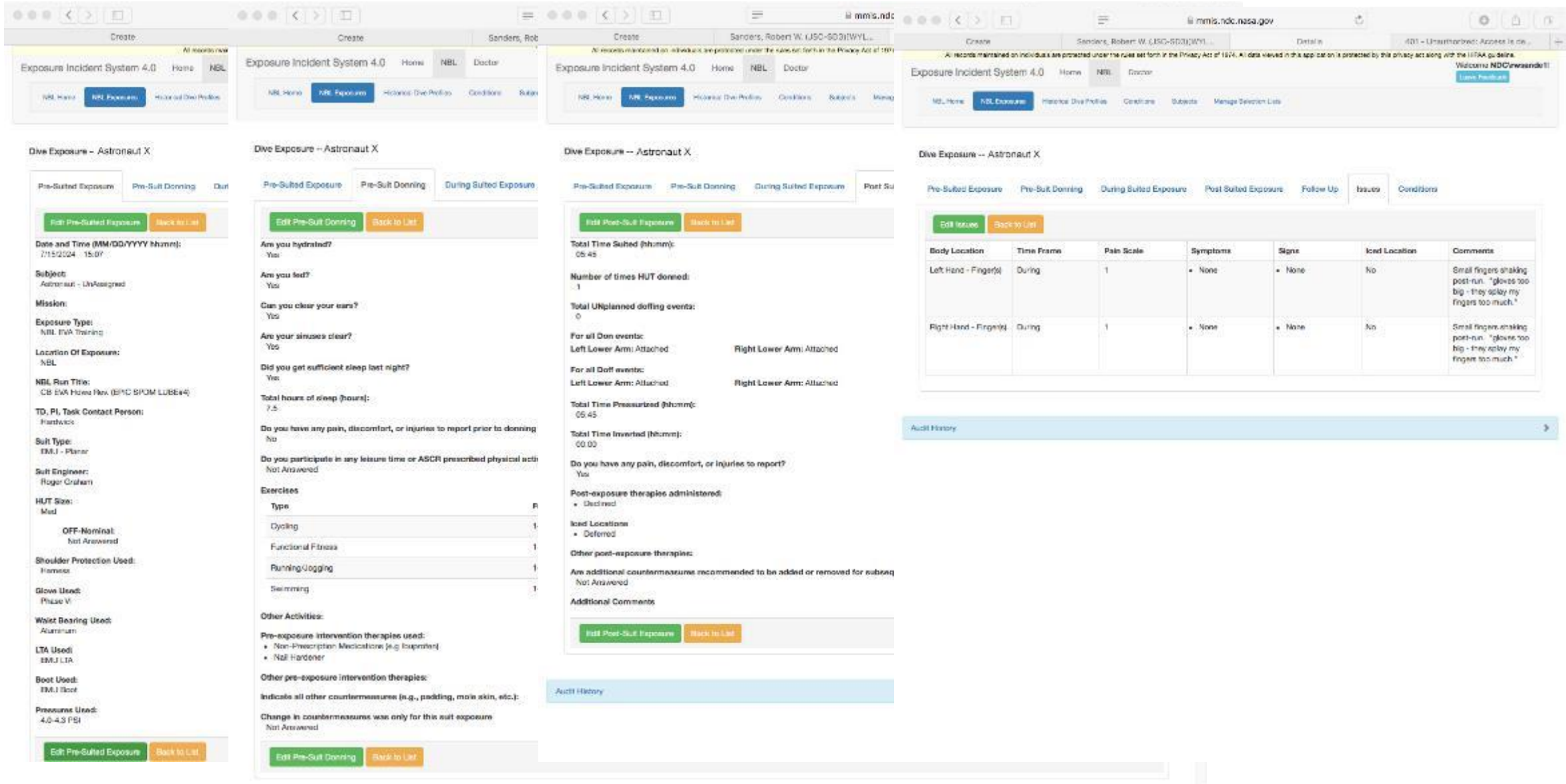
# EIS 2.0


Exposure Incident System 4.0
Home
NBL
Doctor
Welcome NDC\rwsander!
NBL Home
NBL Exposures
Historical Dive Profiles
Conditions
Subjects
Manage Reaction Lists
Dive Exposure – Astronaut X
Pre-Suited Exposure
Pre-Suit Donning
During Suited Exposure
Post Suited Exposure
Follow Up
Issues
Conditions
Edit Pre-Suited Exposure
Back to List
Date and Time (MM/DD/YYYY hh:mm):
7/15/2024 15:07
Subject:
Astronaut - UnAssigned
Mission:
Exposure Type:
NBL EVA Training
Location Of Exposure:
NBL
NBL Run Title:
CB EVA Hotel Rev (EPIC SPOM LUBEs4)
TD, PI, Task Contact Person:
Harbison
Suit Type:
EMU - Planar
Suit Engineer:
Roger Graham
HUT Size:
Med
OFF-Nominal:
Not Answered
Shoulder Protection Used:
Harness
Glove Used:
Phase VI
Waist Bearing Used:
Aluminum
LTA Used:
EMU LTA
Boot Used:
EMU Boot
Pressures Used:
4.0-4.3 PSI
Edit Pre-Suit Donning
Are you hydrated?
Yes
Are you fed?
Yes
Can you clear your ears?
Yes
Are your sinuses clear?
Yes
Did you get sufficient sleep last night?
Yes
Total hours of sleep (hours):
7.5
Do you have any pain, discomfort, or injuries to report prior to donning the suit?
No
Do you participate in any leisure time or ASCR prescribed physical activity?
Not Answered
Exercises
Type
Frequency
Intensity
Duration
Cycling
1-2 times per week
Vigorous
45-60 minutes
Functional Fitness
1-2 times per week
Vigorous
45-60 minutes
Running/Jogging
1-2 times per week
Vigorous
45-60 minutes
Swimming
1-2 times per week
Vigorous
45-60 minutes
Other Activities:
Pre-exposure intervention therapies used:
Non-Prescription Medications (e.g Ibuprofen)
Nail Hardener
Other pre-exposure intervention therapies:
Indicate all other countermeasures (e.g., padding, moist skin, etc.):
Change in countermeasures was only for this suit exposure
Not Answered

# EIS 2.0


Exposure Incident System 4.0
Home
NBL
Doctor
Dive Exposure – Astronaut X
Pre-Suited Exposure
Pre-Suit Donning
During Suited Exposure
Post Suited Exposure
Follow Up
Issues
Conditions
Edit Pre-Suited Exposure
Back to List
Edit Pre-Suit Donning
Edit Post-Suit Exposure
Date and Time (MM/DD/YYYY hh:mm):
Subject:
Mission:
Exposure Type:
Location Of Exposure:
NBL Run Title:
TD, PI, Task Contact Person:
Suit Type:
Suit Engineer:
HUT Size:
OFF-Nominal:
Shoulder Protection Used:
Glove Used:
Waist Bearing Used:
LTA Used:
Boot Used:
Pressures Used:
Are you hydrated?
Are you fed?
Can you clear your ears?
Are your sinuses clear?
Did you get sufficient sleep last night?
Total hours of sleep (hours):
Do you have any pain, discomfort, or injuries to report prior to donning
Exercises
Type
Cycling
Functional Fitness
Running/Jogging
Swimming
Other Activities:
Pre-exposure intervention therapies used:
Non-Prescription Medications (e.g Ibuprofen)
Nail Hardener
Other pre-exposure intervention therapies:
Indicate all other countermeasures (e.g., padding, moisskin, etc.):
Change in countermeasures was only for this suit exposure
Total Time Suited (hh:mm):
Number of times HUT doned:
Total UNplanned doffing events:
For all Don events:
Left Lower Arm: Attached
Right Lower Arm: Attached
For all Doff events:
Total Time Pressurized (hh:mm):
Total Time Inverted (hh:mm):
Do you have any pain, discomfort, or injuries to report?
Post-exposure therapies administered:
Declined
Iced Locations
Deferred
Other post-exposure therapies:
Are additional countermeasures recommended to be added or removed for subsequent suited events?
Additional Comments

# EIS 2.0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Pre-Suit Donning
During Suited Exposure
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Follow Up
Issues
Conditions
Edit Pre-Suited Exposure
Back to List
Edit Pre-Suit Donning
Edit Post-Suit Exposure
Edit Issues
Audit History
Date and Time (MM/DD/YYYY hh:mm):
Subject:
Mission:
Exposure Type:
Location Of Exposure:
NBL Run Title:
TD, PI, Task Contact Person:
Suit Type:
Suit Engineer:
HUT Size:
OFF-Nominal:
Shoulder Protection Used:
Glove Used:
Waist Bearing Used:
LTA Used:
Boot Used:
Pressures Used:
Are you hydrated?
Are you fed?
Can you clear your ears?
Are your sinuses clear?
Did you get sufficient sleep last night?
Total hours of sleep (hours):
Do you have any pain, discomfort, or injuries to report prior to donning
Exercises
Type
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Functional Fitness
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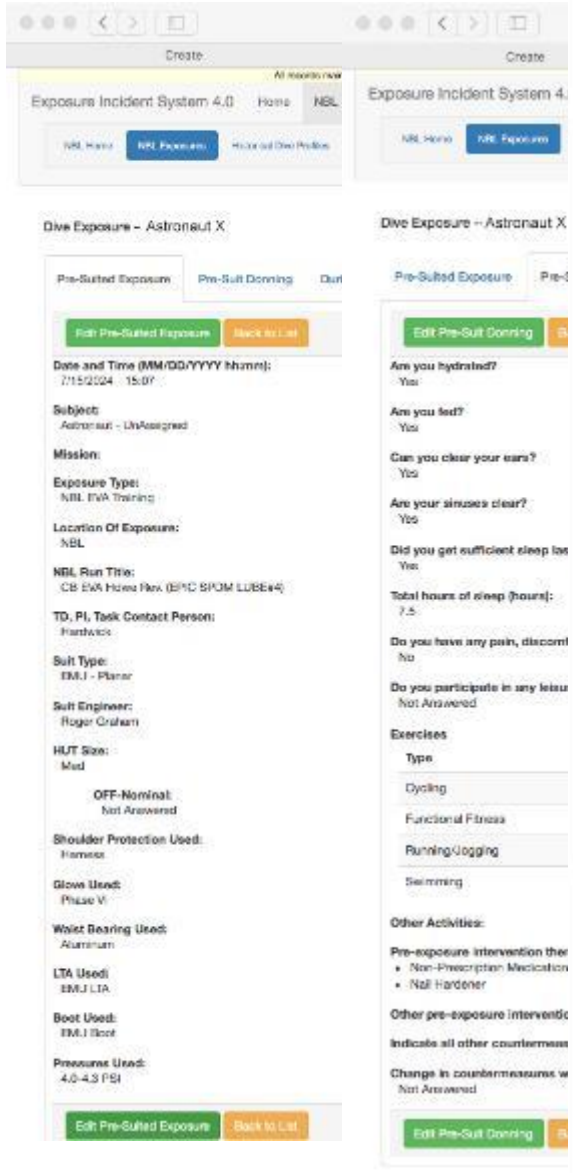
Number of times HUT donned:
Total UNplanned doffing events:
For all Don events:
Left Lower Arm: Attached
Right Lower Arm: Attached
For all Doff events:
Total Time Pressurized (hh:mm):
Total Time Inverted (hh:mm):
Do you have any pain, discomfort, or injuries to report?
Post-exposure therapies administered:
Declined
Iced Locations
Deferred
Other post-exposure therapies:
Are additional countermeasures recommended to be added or removed for subseq
Additional Comments
Body Location
Time Frame
Pain Scale
Symptoms
Signs
Iced Location
Comments
Left Hand - Finger(s)
During
None
No
Small fingers shaking post-run. "gloves too big - they splay my fingers too much."
Right Hand - Finger(s)


Create
Exposure Incident System 4.0
Home
NBL
Dive Exposure – Astronaut X
Pre-Suited Exposure
Pre-Suit Donning
Edit Pre-Suited Exposure
Back to List
Date and Time (MM/DD/YYYY hh:mm):
Subject:
Mission:
Exposure Type:
NBL EVA Training
Location Of Exposure:
NBL
NBL Run Title:
TD, PI, Task Contact Person:
Suit Type:
EMU - Planar
Suit Engineer:
Roger Graham
HUT Size:
Med
OFF-Nominal:
Not Answered
Shoulder Protection Used:
Harness
Glove Used:
Phase VI
Waist Bearing Used:
Aluminum
LTA Used:
EMU LTA
Boot Used:
EMU Boot
Pressure Used:
4.0-4.3 PSI
Edit Pre-Suited Exposure
Back to List
Create
Exposure Incident System 4.
Dive Exposure -- Astronaut X
Pre-Suited Exposure
Edit Pre-Suit Donning
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Are you fed?
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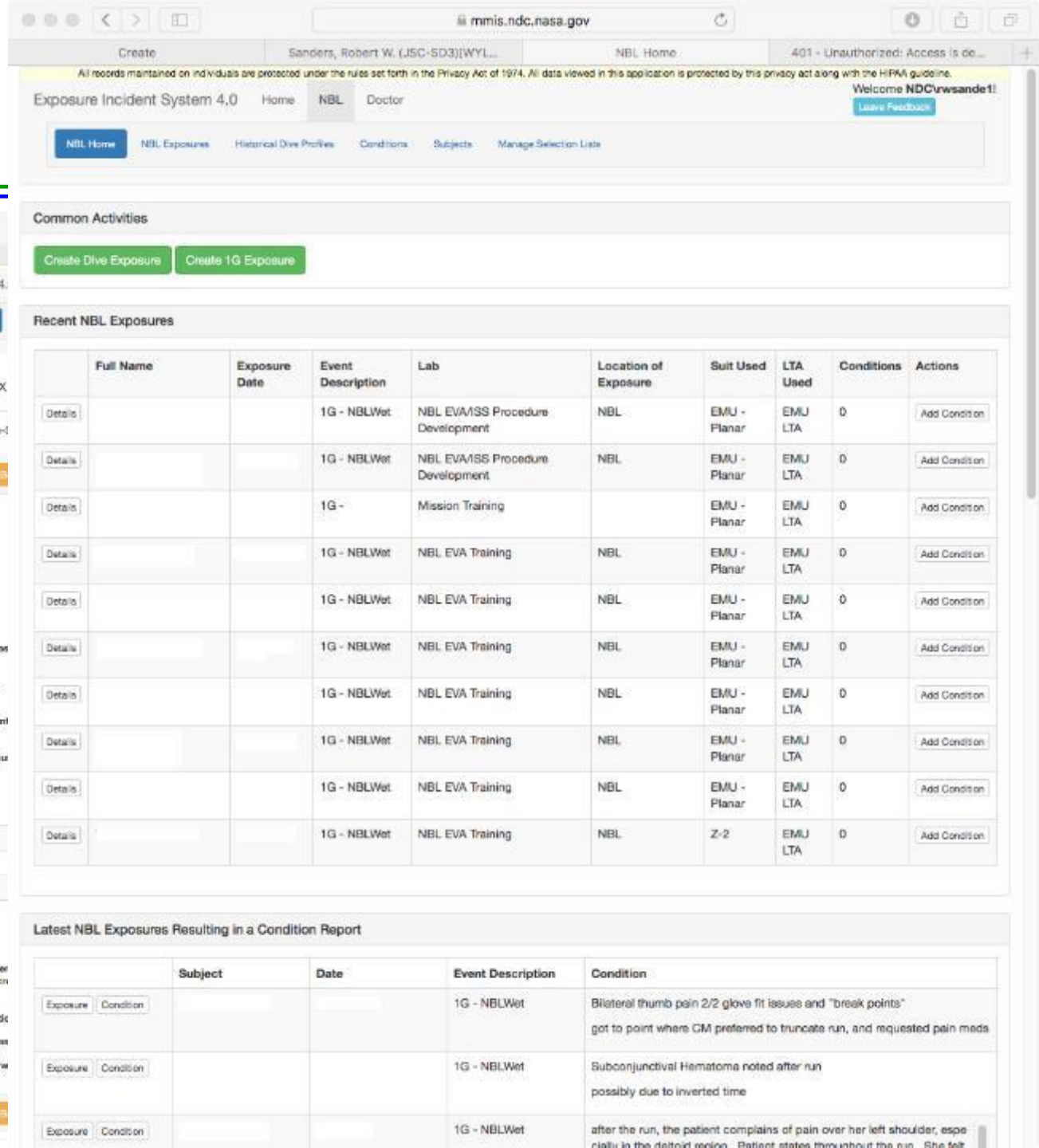
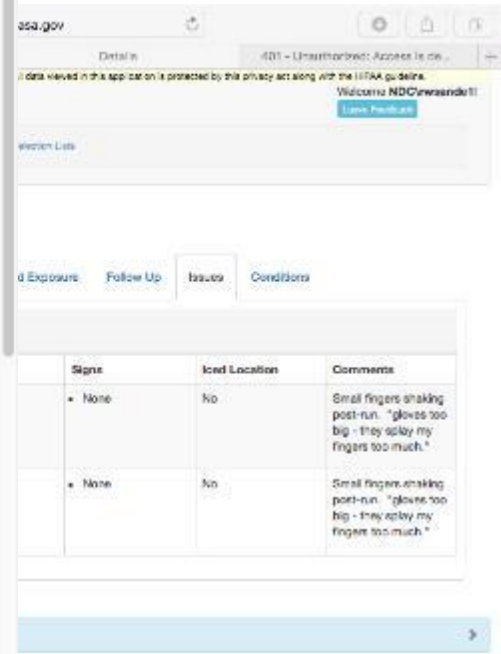
Can you clear your ears?
Yes
Are your sinuses clear?
Yes
Did you get sufficient sleep las
Yes
Total hours of sleep (hours):
7.5
Do you have any pain, discom
No
Do you participate in any leisu
Not Answered
Exercises
Type
Cycling
Functional Fitness
Running/Jogging
Swimming
Other Activities:
Pre-exposure intervention ther
Non-Prescription Medication
Nail Hardener
Other pre-exposure interventic
Indicate all other countermea
Change in countermeasures w
Not Answered
Edit Pre-Suit Donning


mmis.ndc.nasa.gov
Create
Sanders, Robert W. (JSC-SD3)[WYL...
NBL Home
401 - Unauthorized: Access is de...
All records maintained on individuals are protected under the rules set forth in the Privacy Act of 1974. All data viewed in this application is protected by this privacy act along with the HIPAA guideline.
Exposure Incident System 4.0
Home
NBL
Doctor
Welcome NDC\rwsande1!
Leave Feedback
NBL Home
NBL Exposures
Historical Dive Profiles
Conditions
Subjects
Manage Selection Lists
Common Activities
Create Dive Exposure
Create 1G Exposure
Recent NBL Exposures
Full Name
Exposure Date
Event Description
Lab
Location of Exposure
Suit Used
LTA Used
Conditions
Actions
Details
1G - NBLWet
NBL EVA/ISS Procedure Development
NBL
EMU - Planar
EMU LTA
0
Add Condition
1G -
Mission Training
NBL EVA Training
Z-2
Latest NBL Exposures Resulting in a Condition Report
Subject
Date
Event Description
Condition
Exposure
Condition
Bilateral thumb pain 2/2 glove fit issues and "break points"
got to point where CM preferred to truncate run, and requested pain meds
Subconjunctival Hematoma noted after run
possibly due to inverted time
after the run, the patient complains of pain over her left shoulder, espe


Welcome NDC\rwsande1!
Leave Feedback
Follow Up
Issues
Conditions
Signs
Iced Location
Comments
None
No
Small fingers shaking post-run. "gloves too big - they splay my fingers too much."

# Still just learning from mistakes…

- Modeling can *prevent* the need to learn from “misteaks”
  - Proactive
  - Prevent or Decrease injuries
  - New Suit Design – Injury ***prevention***
  - No Need to expose personnel to suit to learn

# Modeling is a Solid Answer

- What we know is from EMU in NBL
  - vetted in microgravity.

.

- No new injury patterns "discovered" in space,
  - our process is "working“

- Imagine the benefit to modeling the suit-human interface…
  - to guide suit use and astronaut training in preventive measures without ever having to injure a crew member
  - For planetary missions, there is no equivalent analog… modeling is our only option

# Thank You!

- *There is no perfect suit… There is no perfect human, but with the proper modeling, we may create the ideal human-suit interface ... with virtually all injuries made a thing of the past!*

# Virtual Fit Check: Parametric Human Body and Suit Models

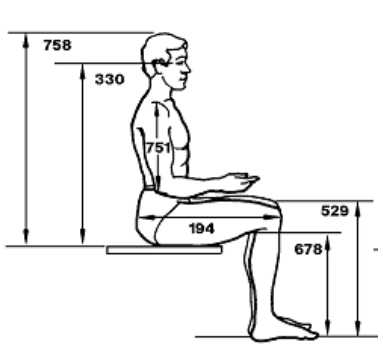
EVA Technology Workshop 2017

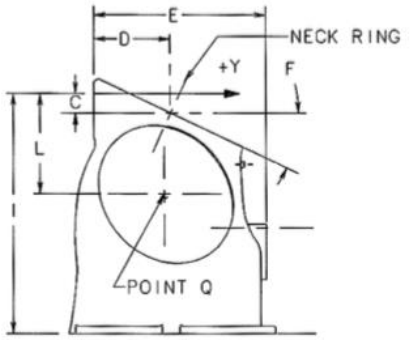
**October 17, 2017**

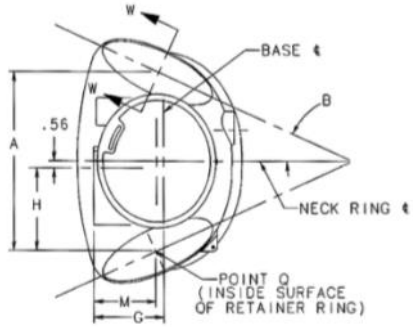
**Han Kim (Leidos)**
**NASA JSC Anthropometry & Biomechanics Facility**

# Predictive Suit Fit Check: Former Techniques

- Linear Measurement Based Technique
  - Compare linear dimensions between suit and crewmembers
  - However, linear measurements do not represent 3-D body and suit geometry



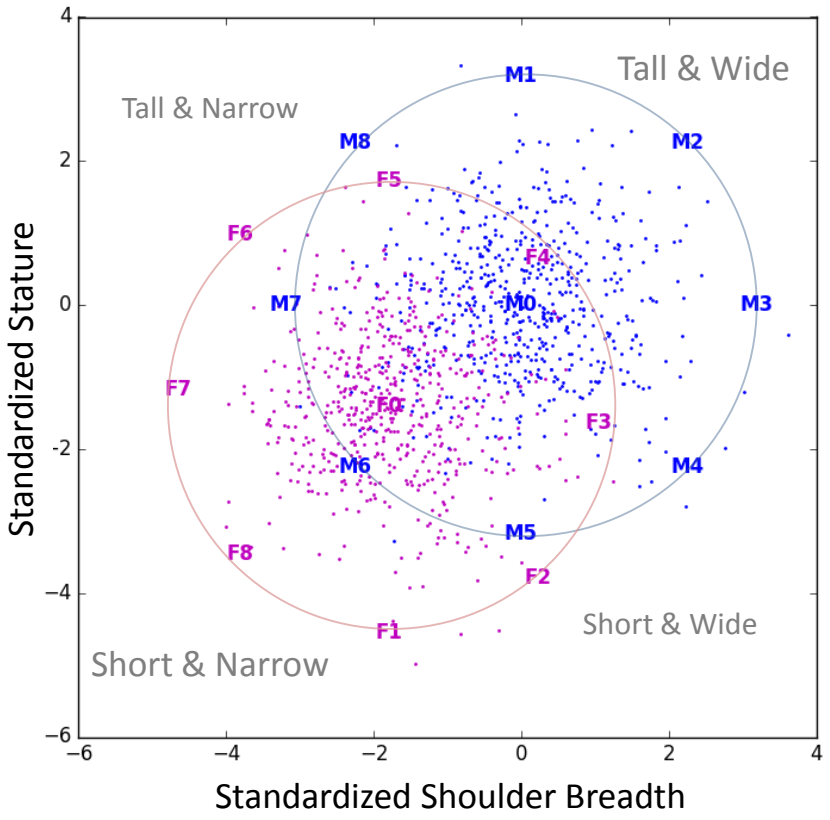




- 3-D Scan Technique
  - Overlay 3-D body scans with CAD drawing to assess overlap and clearance
  - However, scans do not represent the entire ranges of crewmember body shapes

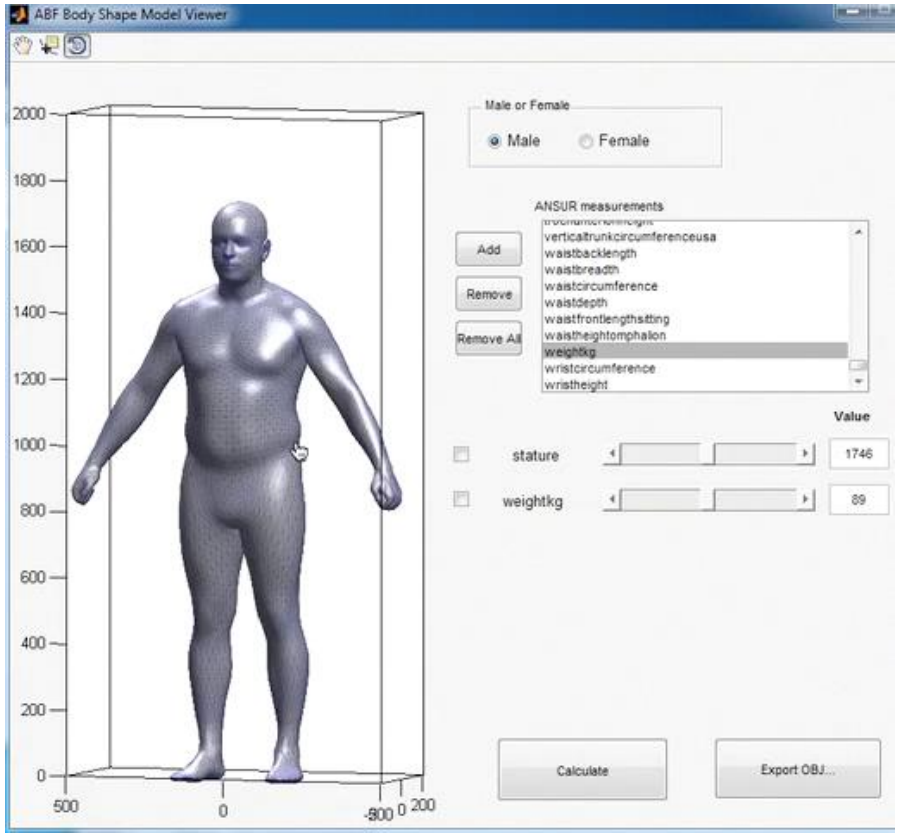
# Boundary Subject Sampling

- Body dimensions were strategically sampled to include 99% of population (“boundary subjects”)
- Formerly used a nearest-neighbor scan data, but at present using a parametric body shape model

Identification of Boundary Subjects

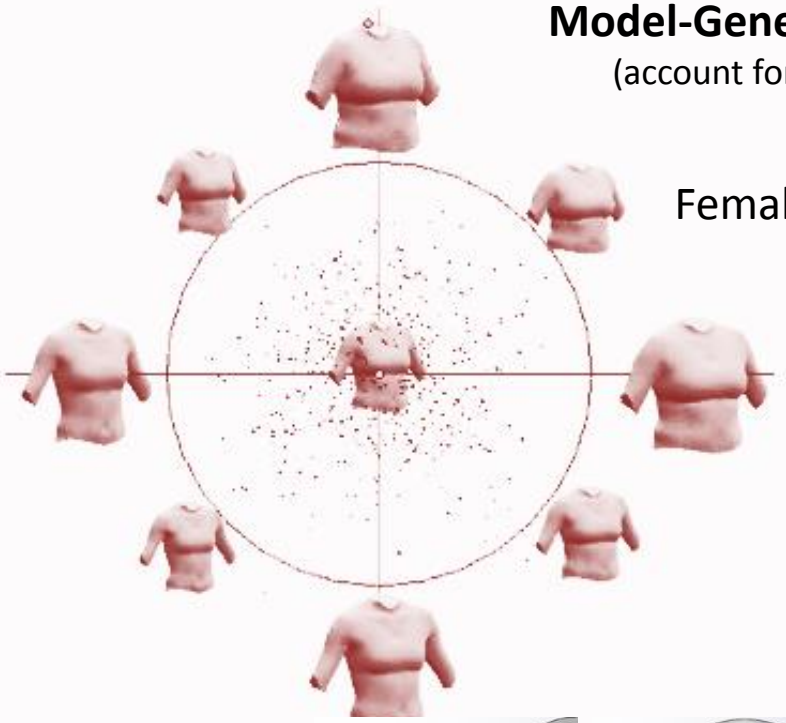



Parametric Body Shape Modeling



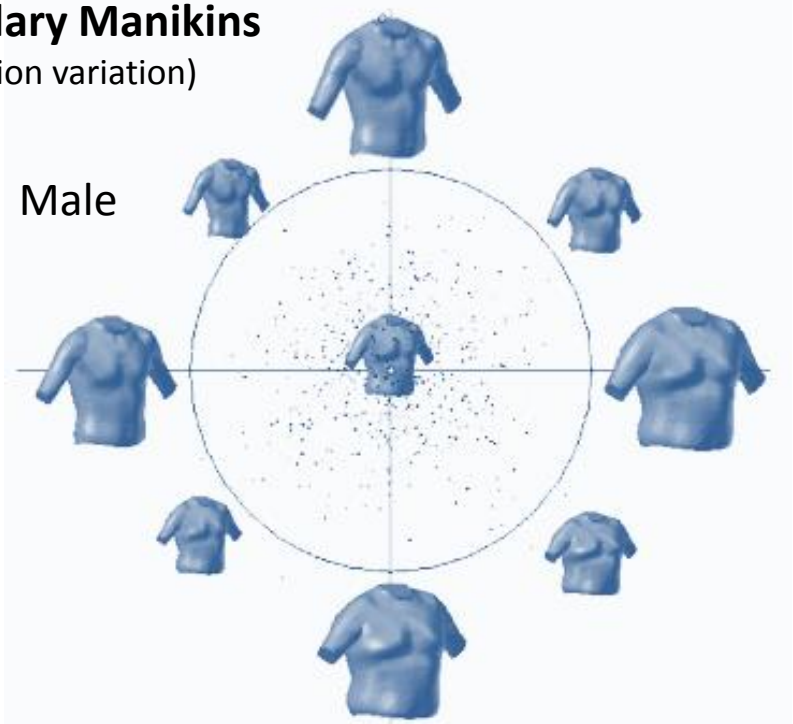
# Boundary Manikin Family

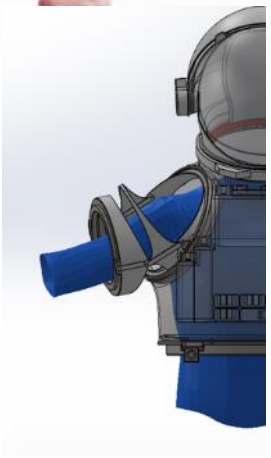
**Model-Generated Boundary Manikins**
(account for 99% of population variation)

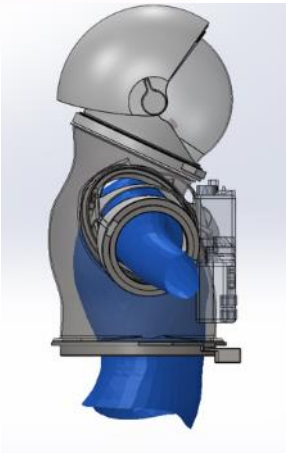


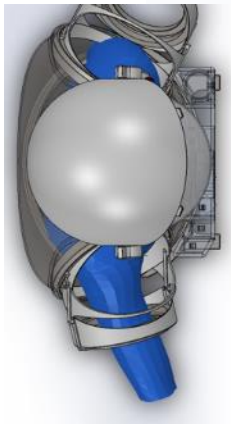
Female

Male









**Virtual Suit Fit Check**:

- Overlay with suit CAD drawings
- Estimation of overlap

# Fit Check Techniques for Large Dataset

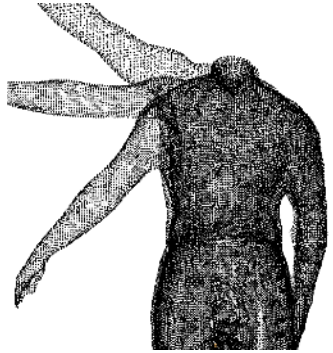
- *Manual* fit assessments become extremely difficult with a large number of suits and body poses


X-Large


Large


Medium

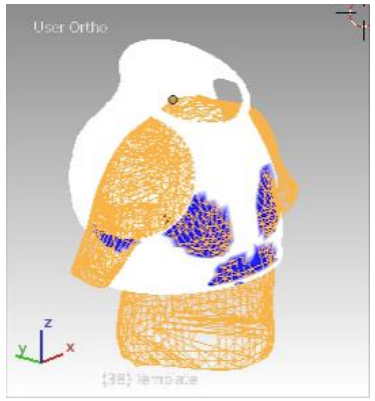
Different Suit Sizes



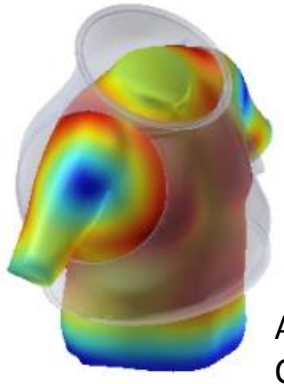
Different Body Poses

18 manikins x 3 suit sizes x 3 poses = 162 tests per iteration

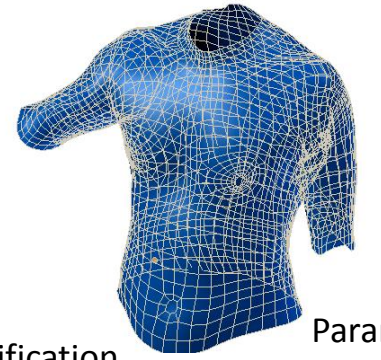
- *Programmatic* techniques were developed to automatize suit positioning and clearance quantification
- A reposable manikin was developed to articulate upper extremity poses




Programmatic
Suit Positioning



Automatic
Clearance Quantification



Parametrically
Reposable Manikins

# Monte-Carlo Suit Fit Assessment

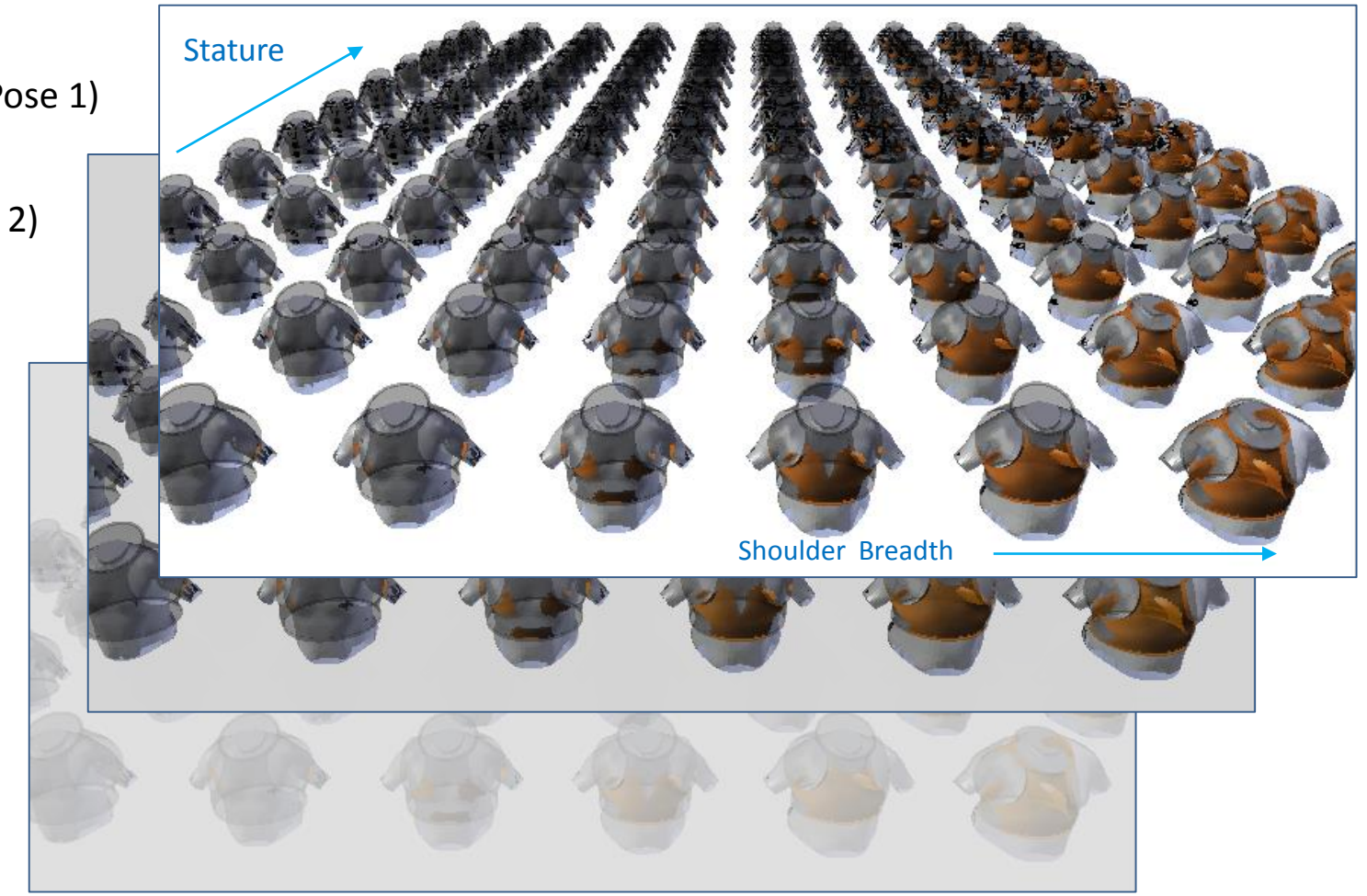
- A large dataset of body shapes will be generated by a parametric model
- Programmatic suit positioning and volumetric assessment applied to models
- All permutations of suit sizes and body poses will be tested for fit assessments

(Suit Size 1, Pose 1)

(Suit Size 1, Pose 2)

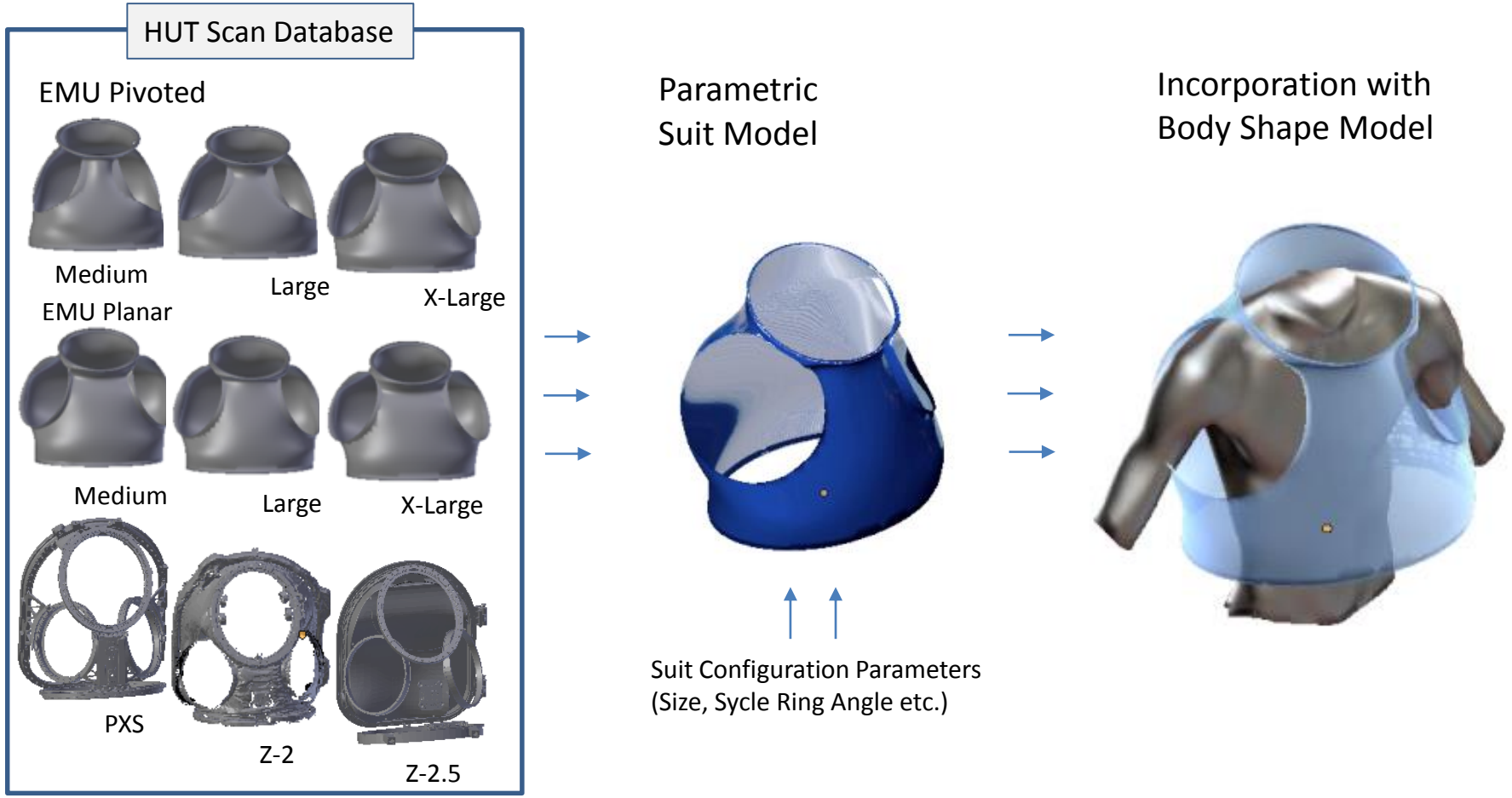
⋮

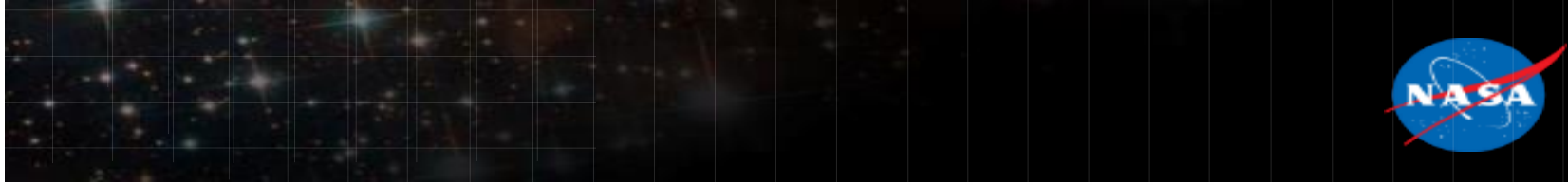
(Suit Size *n*, Pose *m*)



# Future Work: Incorporation with Parametric Suit Modeling

- Previous suit fit check required a end-product CAD or 3-D scan of suit
- In the near future, suit geometry will be parametrically modeled from suit scans
- Suit fit can be predictively assessed for variations of suit configuration and body shape parameters





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# Decision Support Using an Integrated Human-Exosuit Computational Model Framework

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Massachusetts Institute of Technology

October 18, 2017

# Stirling Group Research Goals

Advancing the use of ***wearable sensors*** in ***naturalistic settings*** to enable new insights on the interactions between ***human motor and cognitive performance***

- Quantifying and modeling human biomechanics during operational tasks
- Mapping complex physiological signals to performance metrics
- Assessing how exosystem design parameters influence motor and cognitive performance

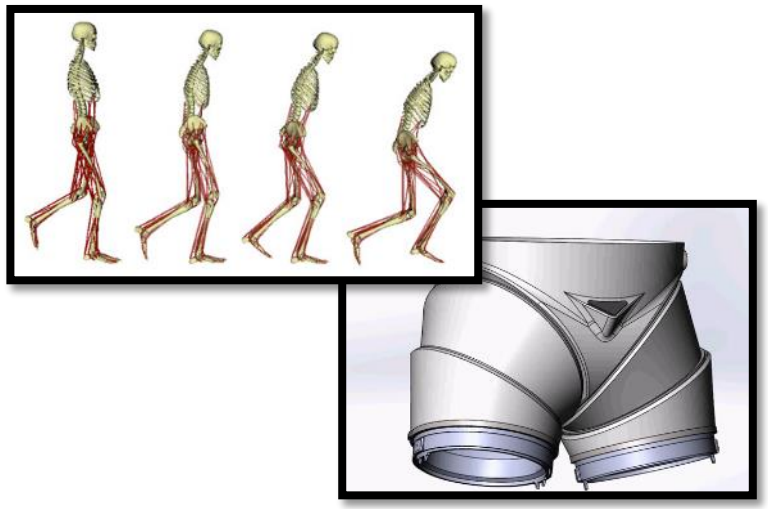
NASA

Occupational Therapy Schools USA

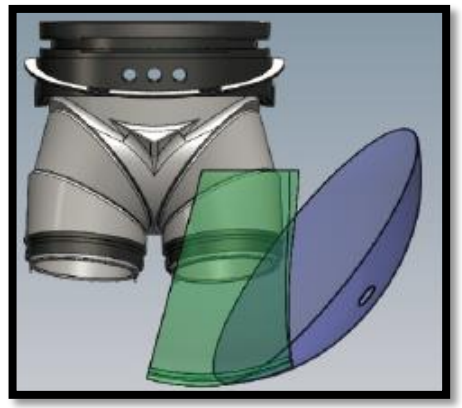
Lockheed Martin

# Current Limitations in Modeling Human-Suit Interaction

- Dynamic Interaction Locations
  - Tools exist for gait and ergonomics, as well as mechanical design
  - No software to allow for design of systems with dynamic interaction locations with the human



- Enabling Natural Range of Motion
  - Natural range is not always enabled in spacesuits
  - Increasing hip circumduction during gait without the spacesuit increases required energy (Shorter, Wu, & Kuo, 2017)
  - Motor limitations can influence cognitive elements of performance (Bequette & Stirling pilot data)

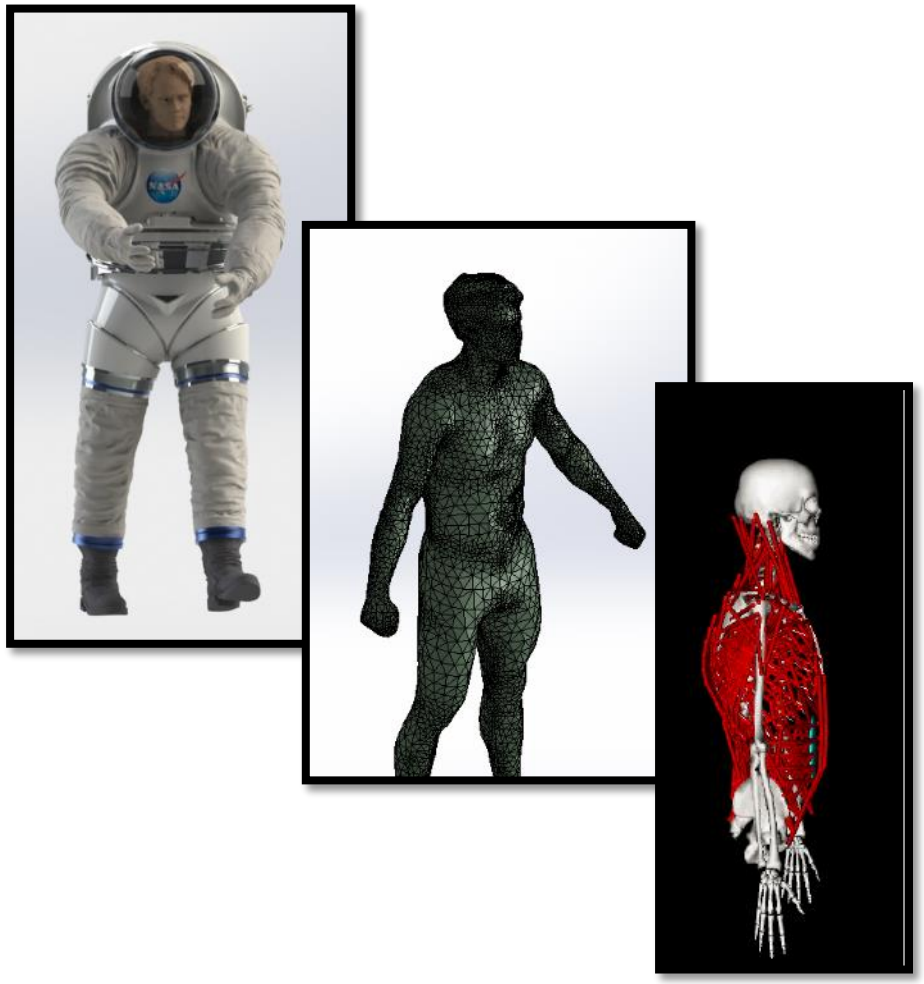


Cowley et al., 2012

# Our EVA-Human Modeling Approach

- Integrate solid modeling, solid mechanics, and musculoskeletal modeling

- Use the relevant pipeline components to assess decisions related to
  - Kinematic fit (static and dynamic)
  - Assessment of sizes required for a population
  - Dynamics of motion for operational tasks
  - Human energy requirements for operational tasks
  - Potential injury mechanisms

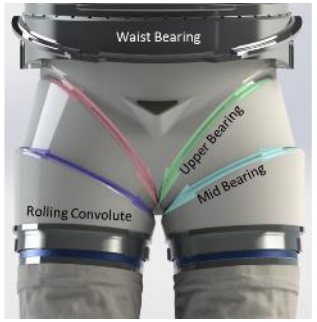


# Current Capabilities Examples: Insights from Solid Models

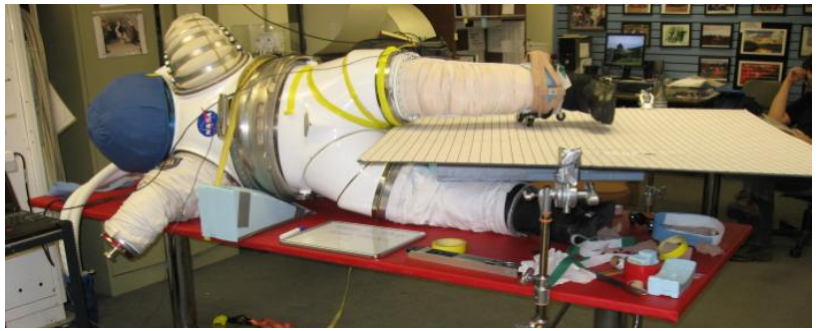
- Informing decisions on locking out joints or placement of bearings
  - Example: The waist bearing range of motion enables a reduced dynamic base during locomotion.

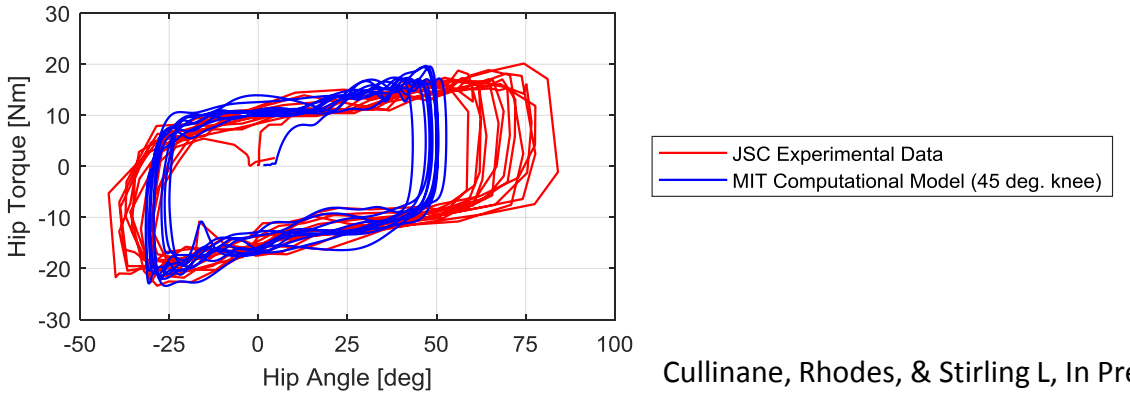
| | Static Base (m) | Dynamic Base (m) |
|---|---|---|
| Unsuited (Measured) | 0.263 | 0.081±0.021 |
| Suited Walking Forward (Measured) | 0.355 | 0.190±0.027 |
| Suited Walking Forward (Model Minimum) | 0.354 | |

Cullinane, Rhodes, & Stirling L, 2017




- Estimating required torques to generate motion or motion from applied torques
  - Example: Validating model dynamics and assessing the contribution of torque to speed and knee alignments






Cullinane, Rhodes, & Stirling L, In Prep

# Example Questions for xEMU Needs

- Range of motion requirements
  - How does including bearings and adapting bearing alignment affect range of motion?
  - How does the natural range of motion compare to the designed range of motion?
- Dynamics of motion for operational tasks
  - What joint torques are required for operationally relevant tasks?
- Considerations in fleet sizing
  - How does selecting a fixed number of sizes affect the fit for a range of anthropometries?
  - What is the lag between human motion and suit motion (i.e., what is the slop)?
  - How does a particular astronaut fit the suit and what indexing would be required?

# Acknowledgements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  - Faculty: Leia Stirling (PI), Raul Radovitzky (Co-PI)
  - Students: Conor Cullinane, Chris King, Aditi Gupta, Patrick McKeen
  - Collaborators: Richard Rhodes (NASA), Shane Jacobs (David Clark Company, Inc.), Dennis Anderson (BIDMC)

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# Panel: EVA Human Modeling

- *Topic Title: Near-term applications and needs of Human-Suit modeling capabilities to inform xEMU development.*
  - Focus on near-term applications of existing models rather than what we could do with better models 5-10 years from now.
  - Are our current models good enough to be helpful? Or do their limitations make them misleading?
  - What EVA-Human models do you already use, if any? What works and what doesn't work?
  - If models are not already being used, why not?
  - What are potential applications of model(s) to xEMU development if they are not already being used? What questions / problems can they address, how soon, and are these actually important problems?